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The Mechanics of the Compound Grinding Mill.

THIS journal is more concerned with the duty and performance of the compound grinding mill, but it may be useful to give some consideration to the mechanical principles upon which the mill works and upon which its performance depends.

It is understood generally that the compound mill is of the tube type, that it rotates at an optimum speed, is charged with media of assorted sizes, is fed at one end with the material to be ground and discharges the finished product at the other end, and that its rotation causes the media to trundle over or otherwise impinge upon the material and reduce the latter in size. If the speed is very low, the action is that of trundling or attrition. If the speed is high the impact force of the falling media may be somewhat violent and relatively sharp blows will impinge upon the grit at the toe of the charge; if the speed is very high there may be a tendency for some of the lightest or smallest particles to adhere to the lining and the amount of grinding done will be limited.

The normal mill is supported upon trunnion journals cast on, or rigidly attached to, the end covers. These journals are supported in self-aligning water-cooled bearings, and provided with good facilities for lubrication; the trunnions are usually hollow to facilitate the admission of the feed and the discharge of the finished product. The mill shell invariably becomes heated and expands during the grinding process; diametral expansion does not usually cause trouble but length-wise expansion needs to be provided for, and it is now usual to support the trunnion bearing, remote from the drive, upon a gang of guided rollers in such a way that the expanded length of the shell determines the position of this bearing; the normal length increase may be, say, $\frac{1}{4}$ in. or $\frac{3}{8}$ in., but under some conditions it is much greater.

The amount of expansion can be kept under control by maintaining a good ratio of media to grit within the mill and by spraying water on the outside of the shell. The former can be effected by limiting the rate of grit discharge through each of the diaphragms, and the latter by using a liberal quantity of water—

as much as 500 gall. per ton of cement ground has been provided for in exceptional cases. This water can be used again if it is conserved, but it will need filtration if the mill building is dusty and the water takes up the impurities; a good-sized reservoir usually proves an advantage.

Speed.

The rotative speed of mills is very important. Mill speeds are often loosely referred to as slow, medium, and high. Engineers and operators often have their own ideas about the speed of mills and the drives are arranged accordingly, but any speed, having been fixed, can seldom be altered except at considerable cost. If the speed has been set too low, special fittings may be applied to the inside of the shell lining to give lifting action. If the speed is too high, the media-grit mass tends to be thrown across the mill and beyond the toe of the charge mass, resulting in poor output and wasted effort; if the speed is very high, the lighter material tends to cling to the surface of the lining. There is a best speed for each condition of loading. There is also a number of possibilities of loading, but at this stage it will be convenient to consider only what may be termed the standard loading of 30 per cent. of the volume of the mill; any material increase on this figure may theoretically call for some increase of speed, but this may be ignored as being too much of a refinement.

It is desirable for the speed of rotation to be based upon, or be a factor of, the critical speed. The critical speed of a mill is that at which small or light particles of definite weight begin to adhere to the surface of the lining, and this speed is obtained by the formula

$$\text{Critical speed} = \frac{54.19}{\sqrt{R}}, \text{ where } R \text{ is the radius of the mill in feet.}$$

A not unusual factor for use in conjunction with this formula is 0.75, and using this figure the working speed becomes

$$\text{Working speed} = 0.75 \frac{54.19}{\sqrt{R}}$$

This formula can be simplified and re-stated thus:

$$N = \frac{200}{\sqrt{d}}, \text{ where } d \text{ is the diameter of the mill in inches and } N$$

the revolutions of the mill per minute. Cases have come to notice wherein the latter factor has been as low as 150 and special fittings were applied to the interior of the mill to obtain lifting action or prevent slipping of the charge. The dash-line curve in *Fig. 1* shows the critical speed of mills covered by the diameters given in the same figure; the full-line curve shows the working speed when the factor 0.75 has been applied. If the mill were used as a finishing mill (a plain tube mill) and all the media were less than, say, 1 in. diameter, there would be no objection to adopting a factor as high as, say, 210 or 215, but either of these figures would result in too high a speed if the media were much above the size named. The critical speed of any mill will become lower as wear of the lining takes place and the diameter of the mill becomes larger.

Fig. 2 (taken from Bulletin No. 146 of the American Institute of Mining Engineers) indicates the ball paths in a mill charge with the mill rotating at 0.75

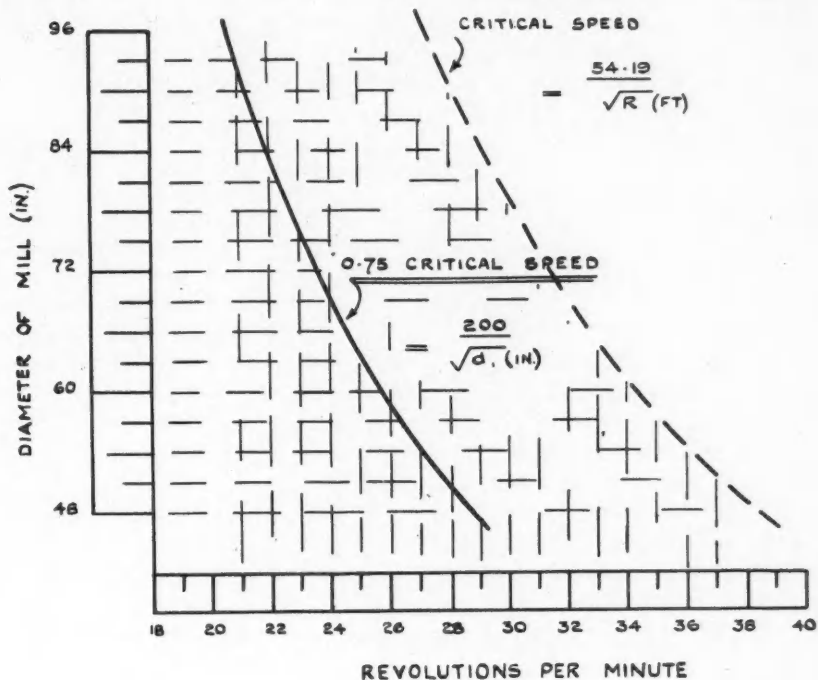


Fig. 1.

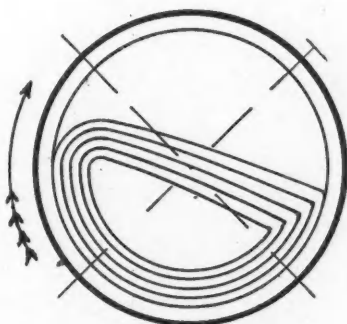


Fig. 2.—Ball Paths in Mills.

the critical speed and when the volume of the charge approximates 30 per cent. of the volume of the mill. The combination of a charge volume of about 30 per cent. with a speed factor of 0.75 the critical speed, and with minimum slipping, appears to produce the maximum height of fall with good cascade movement of the charge mass.

Mill Proportions.

The length-diameter proportions of existing mills varies considerably and is not based on any system. The figures may range between 3 to 1 up to or above 5.5 to 1; in some cases the dimensions and the total pressure capacity of the makers' bending rolls have possibly been the determining factor. It is also probable that operational practice has not given the mill makers a definite lead in this matter; but the large reduction-ratio duty of mills that is now called for (0.5 in. to 0.005 in., or, say, 100 to 1 in a single pass) possibly demands the largest length-diameter ratio mills practicable. Large reduction-ratio duty is possibly attainable in almost any length-diameter ratio, but it will call for more skill on the part of the staff; the mill would also be less flexible and require more careful handling.

Large length-diameter proportions can be more easily obtained when the trunnion end-covers with bearings are discarded and the mill is supported on two slider rings, with "Mitchel" bearing blocks, positioned at about one-fifth of the length of the shell from each end; the design is more economic and there is much in favour of it provided that dust is definitely excluded from the rings and their bearings and that lubrication has proper attention.

Drive.

Mills supported upon trunnion bearings are usually driven by a spur pinion with the spur ring attached to one of the end covers. Mills supported upon slider rings are usually driven through what is termed the central drive. There is much in favour of both methods for their own conditions. The tooth load in each case is high, possibly highest with the central drive owing to the smaller diameter of the last wheel in the gear train. In both cases the gears must be totally enclosed and the lubrication well provided for. The central drive calls for the greatest overall length, and the spur-wheel drive for the greatest width.

Chamber Lengths.

The proportional length of the various chambers in existing mills varies considerably, often as the result of modifications after manufacture. It is generally accepted that 30 per cent. of the net length of the mill is appropriate for the first chamber, and that the position of the various diaphragms is merely a convenient means of maintaining the segregation of different sized media. The length of the chambers must depend to some extent on the range of size of media that is applied to each chamber, as well as on the fineness of the product of the mill. The long first chamber provides some compensation for variation in size of feed, in quantity of feed, and in the variation of hardness, toughness, and grindability of the clinker. In a 4-chamber mill a convenient subdivision of length would be, say, 30 per cent., 25 per cent., 25 per cent. and 20 per cent.

starting from the feed end, but the construction of the shell, the position of the manhole openings, the length of the lining plates, and the drilling of the holes for the lining-plate bolts, are factors that must have consideration.

Fig. 3 shows a section through a typical 4-chamber mill with the proportions given. The diagram also indicates the range of sizes of media used in the various chambers. Lifter diaphragms are indicated in all the intermediate positions. A similar diaphragm with special lifters is also indicated at the outlet end; the latter is now usual if the mill is arranged for the trunnion discharge. The depth of media is indicated for a charge of 30 per cent. of the volume.

Linings.

Linings are always fitted on the inner surface of the mill shell, and also on one or both the end covers. If the surface of the lining is too smooth, or too even, or too regular, the media will not lift as it should whatever the speed of rotation with the result that little grinding will be done and rapid wear of the

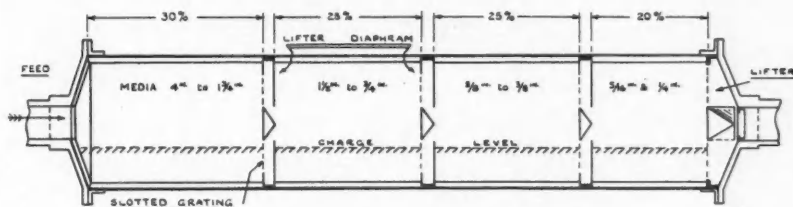


Fig. 3.—Section through Compound Mill.

lining will take place owing to slipping of the mass. If lifters are used to compensate for smoothness of lining or lack of grip they may be a nuisance, when new, owing to the media-grit mass being lifted excessively and possibly thrown across the mill.

Diaphragms.

Diaphragms are important details. They serve principally to maintain size segregation of the media, but they can also be slotted to control the depth of grit in the various chambers. The size of hole or slot in the first diaphragm should also prevent any over-size grit getting past this point. The outlet diaphragm, in conjunction with its lifters, ensures the discharge of the product into the trunnion of the trunnion discharge mill.

Diaphragms may be of the single-plate type in which the grit scrubs both faces of the slotted plate, or they may be of the double-plate (or lifter) type wherein the grit scrubs only the upstream face of the slotted plate. When the single-plate type is used there is a possibility of the smaller media, or chips of media, or foreign matter, getting into the enlarged side of the slot and gradually blocking it up; this condition can never arise with the lifter type.

The inner radius of the plain area, outside the slotted area, of all diaphragms should be arranged to control the working depth of the bed of grit on the up-

stream side and so prevent that chamber becoming starved of grit whatever the rate of feed.

Media.

The usefulness and value of correct classification of media are now more fully appreciated. The value of a good ratio between media size and clinker and grit size is also more fully understood—large balls and media are rarely found towards the finishing end of a mill, and small balls and media are rarely found at the feed end of a mill.

Approved media are made up of high-carbon forged-steel balls for the feed end of the mill. For normal duty on clinker from rotary kilns, the diameter need not be greater than, say, 3 in. ; 4 in. should be regarded as the maximum under any conditions. These balls should be followed by cast (white) iron pellets of from, say, $1\frac{1}{4}$ in. to $\frac{3}{4}$ in. diameter, the length being, say, from $1\frac{1}{2}$ to $1\frac{1}{4}$ times

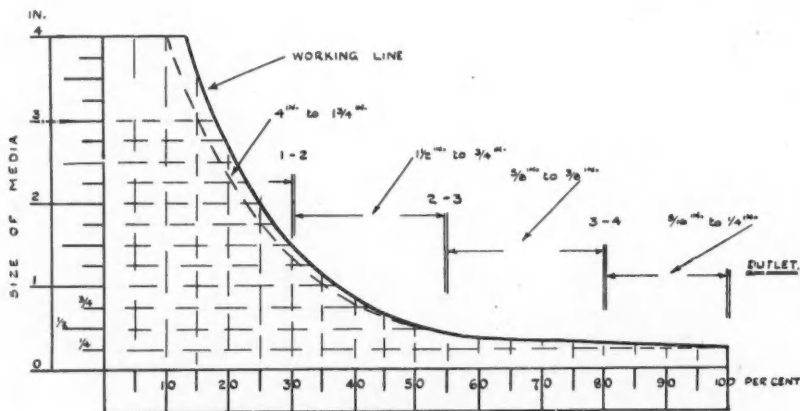


Fig. 4.—Curve for Grinding Media.

the diameter. The pellets should be followed by "slugoids" of from $\frac{5}{16}$ in. to $\frac{1}{16}$ in. or even $\frac{1}{8}$ in. diameter, with the length as above ; these should be of high-carbon steel, hardened to give a longer life. The density of the whole of these media may be taken at 470 to 480 lb. per cu. ft., and the bulk weight at 260 to 265 lb. per cu. ft. A fair figure for the voids in the mass would be, say, 45 per cent. ; all figures for weight and voids need a reasonable tolerance.

Fig. 4, adapted and amplified from the lower curve in the similar diagram given in our issue for May, 1942, indicates the proportionate sizes of media suitable for the progressive reduction of grit in mills of this kind. In any case the initial charge can be based upon it, and if adjustments are found necessary they can be carried out later and based upon experience. The classification should be suitable for most clinkers having a maximum diameter of $\frac{3}{8}$ in., or even $\frac{1}{2}$ in. if the proportion of this larger size is not too great, and for producing a superfine cement

having a residue of only, say, 1 per cent. on the 170-mesh sieve. The classification would also give good service for a product having a residue of, say, 8 or 10 per cent. on the same sieve.

A summary of the size analysis of the media based upon the curve and assigned to the various mill chambers is as follows: it should be pointed out, however, that the figures given are of only a very general nature—the principle is more important than detail.

	Per cent.
First chamber:	
4 in.	15
3 in., 2½ in., 2 in., 1¾ in. (in equal quantities)	15
Second chamber:	
1½ in., 1¼ in., 1⅓ in., 1 in., ⅞ in., ¾ in. (in equal quantities)	25
Third chamber:	
⅝ in., ½ in., ⅙ in., ⅓ in. (in equal quantities)	25
Fourth chamber:	
⅝ in. and ¼ in. (in equal quantities)	20
	<hr/> 100 <hr/>

The total charge has a weight of 42 tons and the fractional quantities shown are based upon that weight.

An analysis of the classification confirms that a typical batch of this media weighing 1 ton would comprise 150,000 to 200,000 separate pieces; a 42-ton charge would therefore contain between 6 million and 8 million pieces. It is estimated that each piece makes 1½ cycles, or strikes 1½ impact blows, during each revolution of the mill, and if the mill makes 22 revolutions per minute the complete charge will make 200 to 250 million impact blows per minute.

If the construction of the mill does not permit the proportional length of the chambers to be as desired it will be necessary to review the point of division of the media shown on the table, but the media group as a whole should be retained, also as nearly as practicable, to a constant weight per foot run throughout the mill. This example has been dealt with in detail to demonstrate the method.

At first sight it would appear that much of the media is on the small side and that its working life, before it becomes too small for use, will be short. It may be stated, however, that (1) larger media would not so effectively reduce the grit to the size desired, and (2) the rate of wear of the small media when grinding to this low residue will be low, possibly owing to most of the sharpness having worn away and the grit having lost its cutting propensity.

Wear of media is always more rapid at the feed end of the mill than at the finishing end; it may be even three or four times as great, especially when the proportion of superfine cement ground is at all large. Under normal conditions the loss of media may be between 0.5 lb. and 0.75 lb. per ton of ordinary cement ground, and the larger quantity may be distributed between the four chambers in the ratio of, say, 0.4, 0.2, 0.1, and 0.05 lb. respectively. A large mill dealing with up to 4,000 tons of ordinary cement per week, may thus call for a total

make-up quantity of 20 cwt. to 25 cwt. per week. Rate of media wear may be kept down by maintaining a good bed of grit in the various chambers and so avoiding the continued impact of steel upon steel.

Media reduced in size by wear may be transferred to the next chamber downstream, but its life will gradually become less owing the outer skin-hardened surface having been worn away. Many factors influence the rate of wear of media, and any figures given may prove unreliable owing to the many factors that influence it.

Power.

It need hardly be stated that the power used for driving any mill is principally that necessary for trundling, lifting, and agitating the media and grit. This may amount to or about 14 h.p. per ton of the media in a mill of 5 ft. diameter, up to about 16 h.p. per ton in a mill 8 ft. in diameter, when the mills have a charge volume of about 30 per cent. and rotate at a basis speed of 0.75 the critical speed; the friction losses of the bearings and driving gear should not be greater than 3 per cent. or 4 per cent. of the power.

For a long time it was thought that the effort necessary to start up a mill and bring it to speed was two or three times that necessary to keep the mill in operation, but calculations show that the $W \cdot R^2 N^2$ figure for a 42-ton charge in a mill 7 ft. diameter designed to operate at 22 revolutions per minute is much lower than that of the rotor for the 750 revolutions per minute motor suitable for driving the mill; these comparable figures indicate that a large starting-up torque reserve is not required.

The overall efficient working of any mill can only be judged by the H.P. hours or the kW hours used per ton of product having certain residues on selected sieves, or containing a certain percentage of flour, or which contains a certain amount of surface per pound weight. A measure of the efficiency of the separate chambers can only be determined by taking a complete set of samples from the full length of the mill and plotting a residue-reduction graph as described in this journal for May, 1942. This procedure will call for careful work, but the labour involved will be fully compensated for in the interest it provides. The graph as drawn can then be compared with that plotted in the number referred to, and any corrections that are necessary to either the mill or media can be applied; it may be necessary to obtain and work up two or three sets of samples and graphs to ensure a fair average of working conditions.

By-products from Rotary Lime Kilns.

THE recovery of a number of chemical compounds from the rotary lime kiln is the subject of an article by Mr. Ralph Gibbs in a recent number of "Rock Products," of which the following is an abstract.

Nitrogen.

The recovery of nitrogen from rotary kiln gases should not be difficult. Scrubbing the gases with an abundance of fresh water will remove the carbon dioxide and sulphur dioxide and the finely divided particles of dust. If an extremely pure nitrogen is required, the commercial nitrogen can be compressed, liquefied, and distilled to the desired purity. *Fig. 1* is a flow diagram for the production of commercial nitrogen. This can be made to combine with other substances under suitable conditions to form valuable compounds. Thus at 1,800-1,900 deg. F. it will combine with calcium carbide to form calcium cyanamide. This process is used on a commercial scale in those sections of the country where calcium carbide is manufactured. It is possible that a self-contained plant could be developed to produce this commodity.

Nitrogen in the presence of hydrogen and an adequate catalyst, and under suitable conditions of temperature and pressure, will combine to form ammonia.

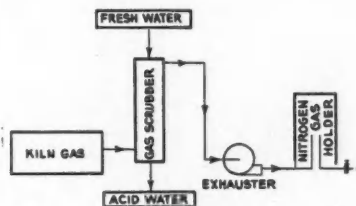


Fig. 1.

The hydrogen generally is obtained from water gas or from the electrolytic dissociation of water. In Serpek's process, a mixture of alumina and carbon is heated to 3,000 deg. F. in the presence of nitrogen when aluminium nitride is formed. Aluminium nitride with water will form ammonia and alumina, the latter being returned to the process to repeat the cycle. An older process is that in which barium oxide and carbon are raised to a high temperature in the presence of nitrogen, when barium cyanide is formed. The barium cyanide can be decomposed by steam at approximately 850 deg. F. with the formation of ammonia, carbon monoxide, and barium oxide, the latter being returned to the process for recycling.

Carbon Dioxide.

One 8-ft. by 125-ft. rotary kiln burning lime with bituminous coal for fuel will exhaust 160 tons of carbon dioxide per day. The separation and purification of the carbon dioxide in rotary kiln gases is not a difficult problem. *Fig. 2* is

a flow diagram for such a process. The exit gas from the kiln is first scrubbed with water to eliminate the sulphur dioxide and wash out the solid particles or dust. From the scrubber the gases, now substantially carbon dioxide and nitrogen, are passed to the absorbers where the carbon dioxide is extracted from the gas by a suitable solution. This solution for selectively absorbing the carbon dioxide can be composed of sodium or potassium carbonate, or even certain organic substances. Such organic solutions very effectively absorb carbon dioxide and triethanolamine is one of this family. From the absorbers come the unabsorbed nitrogen and the carbon dioxide-bearing solution. The nitrogen, substantially pure, can be utilised as described. The solution of carbon dioxide passes through heat exchangers to the lye boiler where the temperature is raised to the boiling point and the pure carbon dioxide is driven out of solution and collected in a

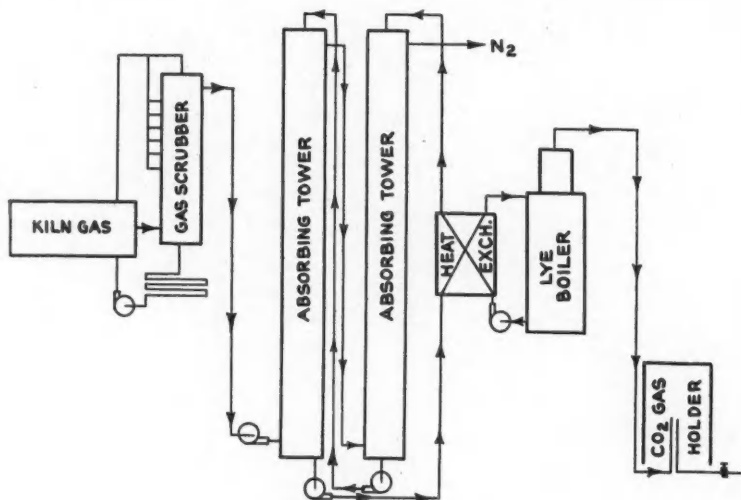


Fig. 2.

gas holder for further processing. The weak absorbing solution is returned to the absorbers and thus repeats its cycle. The diffusion method of separating nitrogen from carbon dioxide is worthy of further investigation.

Liquid and Solid CO_2 .

In the manufacture of liquid carbon dioxide it is only necessary to compress the carbon dioxide to its corresponding pressure. The critical temperature of carbon dioxide is about 89 deg. F. so that its temperature must be below this to obtain the liquid variety. Fig. 3 is a flow diagram of a liquid carbon dioxide plant. Fig. 4 is a flow diagram of a solid carbon dioxide plant where only the basic equipment is shown. In the separation of carbon dioxide from the nitrogen, usually the previously mentioned solutions are used for the absorption of the gas.

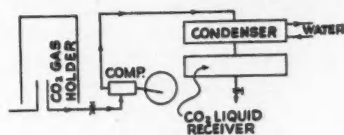


Fig. 3.

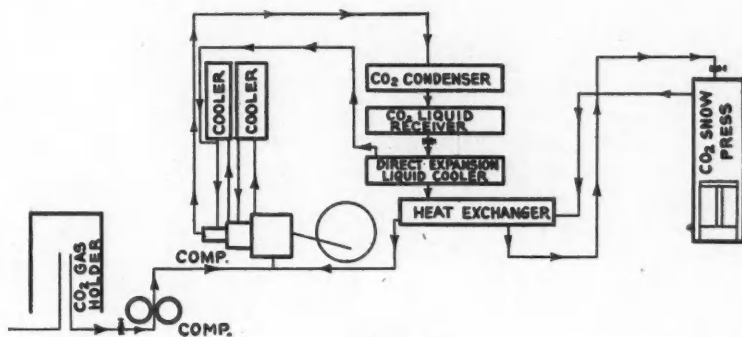


Fig. 4.

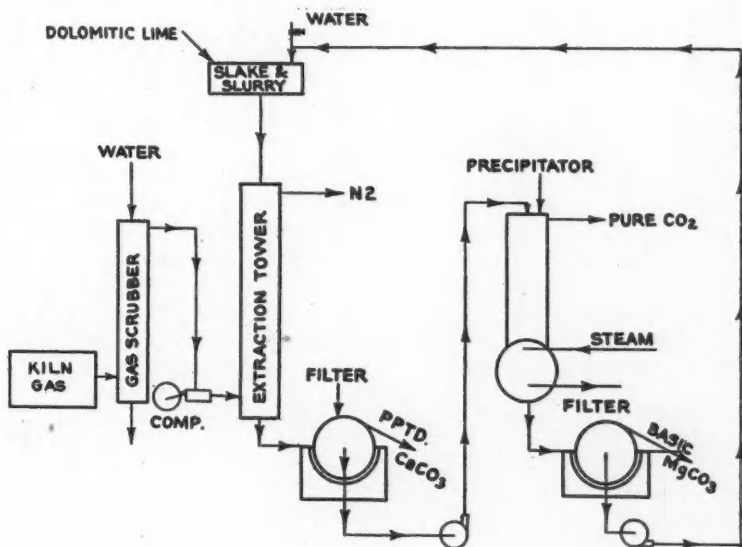


Fig. 5.

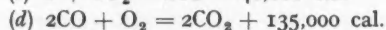
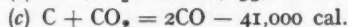
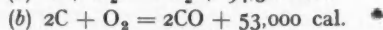
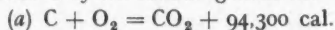
There are, however, other possibilities such as the case of separating the calcium oxide from magnesia of dolomitic lime. *Fig. 5* is a flow diagram for such a process whereby the lime is separated from the magnesia and pure carbon dioxide also is produced. In this process the soft-burned dolomitic lime is slaked to a slurry and pumped into the extractors. The exit kiln gases are scrubbed with water, and then pumped into the extractor. In the extractors the carbon dioxide combines with the hydrated lime to form insoluble calcium carbonate, while the magnesia forms the bi-carbonate which is soluble in the solution of carbonic acid. The solution of magnesium bi-carbonate with the suspended insoluble calcium carbonate is passed from the extractors to the filters where the insoluble calcium carbonate is removed.

The solution containing the magnesium bi-carbonate in solution now goes to the boiler where its temperature is raised to the boiling point and the half-bound carbon dioxide is driven out of solution. In so doing the magnesia is precipitated as basic magnesium carbonate. This suspension of the basic magnesium carbonate is passed from the boiler to another filter where the solid basic magnesium carbonate is removed. The spent solution is returned to the slaking vats for recycling.

In this process are obtained nitrogen, precipitated calcium carbonate of high purity, carbon dioxide, and basic magnesium carbonate of high purity. Thus are produced pure carbon dioxide either for liquefaction, solidification, or any of the purposes for which carbon dioxide is used. In some instances the carbon dioxide is returned to the system at the extractors since the amount of magnesia that will be held in solution is proportional to the partial pressure of the carbon dioxide in solution. Attempts to separate the carbon dioxide from the nitrogen by high pressure and liquefaction have not proved commercially successful. Very high pressures are encountered and this means high power costs. Furthermore, there appears to be some difficulty in securing the expected liquefaction of the carbon dioxide in the presence of so much inert nitrogen.

Carbon Monoxide.

Carbon monoxide is generally the result of the incomplete combustion of carbon. It seems possible that by recycling rotary kiln exit gas through a bed of carbonaceous material, with a supply of air just sufficient to bring about the reduction of the carbon dioxide, an excellent fuel gas will result. This thought has been aroused by the following relations* :—



From (a) we see that 32 gramme molecules of oxygen will combine with 12 gramme atoms of carbon to form 44 gramme molecules of carbon dioxide and liberate 94,300 heat units. From (b) 32 gramme molecules of oxygen will combine with 24 gramme atoms of carbon to form 56 gramme molecules of carbon monoxide

* "Principle of Chemical Engineering." Walker, Lewis and McAdams, 1937 Ed., p. 173.

and liberate 53,300 heat units. From (c) 44 gramme molecules of carbon dioxide will combine with 12 gramme atoms of carbon to form 56 gramme molecules of carbon monoxide and in so doing will absorb 41,000 heat units. From (d) 32 gramme molecules of oxygen will combine with 56 gramme molecules of carbon monoxide to form 88 gramme molecules of carbon dioxide and liberate 135,300 heat units. (b) shows the chemical action which produces carbon monoxide and liberates 53,300 heat units. Equation (c) shows the absorption of heat necessary to reduce carbon dioxide to carbon monoxide, which is 41,000 heat units. Thus, if there were no thermal losses, the burning of 24 gramme atoms of carbon with 32 gramme molecules of oxygen will produce sufficient heat to reduce approximately 56 gramme molecules of carbon dioxide to 73 gramme molecules of carbon monoxide. Thus are produced a total of 56 gramme molecules of carbon monoxide by (b) and 73 gramme molecules of carbon monoxide by (c), a total of 129 gramme molecules of carbon monoxide. Equation (d) shows that there are available 312,000 heat units in the resultant gas.

Carbon monoxide can be produced from carbon dioxide without the inclusion of atmospheric nitrogen, and will be of such purity that it will find uses as a raw material for the making of many chemical substances. The synthesis of methanol is brought about by combining carbon monoxide and hydrogen. Many other organic compounds have been synthesised from carbon monoxide and no doubt many more applications will be developed.

The Use of Small Coal.

It is estimated that about 25 million tons of coal less than $\frac{1}{8}$ in. in size are unavoidably produced every year in the ordinary course of mining in this country. In peace-time such small coal is not favoured by users due to its high ash and moisture content, although a great deal of it is used for steam raising at collieries. In order to find means of improving this small coal, and to find new uses for it, a conference on "The Problems in the Utilisation of Small Coals" was held in London in November, 1943, and the proceedings are now available in book form. This important symposium, comprising about 300 pages and 28 papers by leading authorities on the subject, together with reports of the discussions on the papers, is published by the British Coal Utilisation Research Association, of 13, Grosvenor Gardens, Westminster, S.W.1; the price is 15s. The conference was divided into three sessions, one dealing with the utilisation of small coals and slurries, one with the utilisation of fuels of high inert content, and one with the up-grading of fuels. At a time when it is necessary that every material with a fuel value should be turned to account, this volume is particularly valuable.

The Effect of Alkalis in Portland Cement on the Durability of Concrete.

FIELD observations, confirmed by laboratory tests, have demonstrated the reactive character of concrete aggregates derived from lavas of the volcanic cone of Mt. Rainier, Washington. Deterioration has been universal in concrete containing such aggregates and high-alkali cement, but when low-alkali cements have been used structures are in excellent condition at ages up to 19 years. The rate of retrogression is dependent on the severity of climatic conditions. Disintegration of another type is progressing in certain structures in Eastern Washington. Reactivity of the aggregates used is not exhibited in the sealed-can test but may be demonstrated by a combination of moist storage followed by cycles of freezing and thawing. The main, if not the sole, factor influencing disintegration in this test is the content of alkali in the cement, whether it is present initially or is added at the time of mixing.

The problem is discussed in a paper by Mr. Bailey Tremper in the "Journal of the American Concrete Institute" for November, 1944, where reference is made to the alkali content of cement as used in structures ranging from 6 to 19 years of age. Actual analytical data of alkali content are not available for the cements used at that time, but there are means of estimating it. Since 1939 routine analyses made at frequent intervals show that the percentages of the alkalis Na_2O and K_2O are fairly constant in each brand and type of cement. Reference is made on this basis to high-alkali cement as that containing more than 0.9 per cent. alkalis; medium-alkali cement, from 0.6 per cent. to 0.9 per cent. alkalis, and low-alkali cement, less than 0.6 per cent. alkalis.

In 1941 the writer described the condition of concrete structures containing reactive aggregates from the Cowlitz river in the vicinity of Mt. Rainier, Washington, and it was stated that those structures in which low-alkali cements were used were in excellent condition. In view of the fact that some writers have questioned the permanent integrity of concrete containing reactive aggregates even though the cement was low in alkalis, it is of value to note that these structures, some of them now 19 years of age, remain in nearly perfect condition. Since 1941 the structures containing high-alkali cements have continued to deteriorate, and it is evident that the progress of retrogression has not yet stopped. This is indicated by comparison of photographs and by measurements of cracks over periods of several years. In the more protected parts of the substructures new cracks have appeared recently. Newer structures now appear similar to the older ones at comparable ages.

The sand and gravel in bars of the Cowlitz river is derived in part from lavas of the volcanic cone of Mt. Rainier. These lavas, largely andesitic in composition, have been suspected as constituting the reactive portion of Cowlitz river aggregate. Recent evidence tends to confirm this theory. Aggregates consisting of sand and gravel taken from the White river were used in 1935 in the construction of Deadwood Creek bridge; the bar from which the aggregates were taken

is close to the source of the river in glaciers on Mt. Rainier and is practically undiluted with rocks from other sources. A high-alkali cement was used in the bridge. The concrete showed signs of abnormal cracking as early as 1940, but it was not until 1942 that it became evident that the rate of deterioration was greater and that the probable condition of the concrete would be worse at equal ages than that in the structures constructed with Cowlitz river aggregates.

Laboratory Studies.

At the time of writing the 1941 report, laboratory investigations had not progressed to the point that definite conclusions as to basic causes were warranted.

Four-inch cores cut from the substructures of Clear Fork Creek and Summit Creek bridges (each constructed with high-alkali cement) were stored in the laboratory fog-room at 70 deg. F. During a period of about one month, clear viscous beads and small white patches appeared in considerable number on the surfaces of the cores. The chemical analysis of these exudations is given in Table I. One core, 15 in. long, was found to have a modulus of elasticity determined dynamically of 4,800,000. This value indicates some retrogression in strength since laboratory-made specimens of similar mixtures have reached values of about 6,000,000 at the age of one year.

TABLE I.

Loss on ignition	Per cent.
Insoluble in water (ignited basis)	16.1
Water-soluble (ignited basis)	9.1
	90.9
	Per cent.
SiO ₂	85.0
R ₂ O ₃	2.2
CaO	2.0
Na ₂ O	4.4
K ₂ O	1.9
	95.5

Cowlitz river aggregate when mixed with high-alkali cements expands continuously, with no indication of diminishing rate up to 40 months, the age of the oldest specimens. In general, aggregate from White river gives more rapid and greater expansion. In no case have specimens containing low-alkali cements expanded a significant amount. The addition of 1 per cent. sodium hydroxide (NaOH) to a low-alkali cement has resulted in expansions comparable with those obtained with high-alkali cement. Inspection of the structures containing Cowlitz river aggregate and high-alkali cement has indicated that the severity of exposure to climatic conditions has been a major influence in the rate, though possibly not the final degree, of deterioration of the concrete. Laboratory tests have been made to study the influence of freezing and thawing on the durability of concrete containing Cowlitz and White river aggregates when mixed with cements of varying alkali content.

Test bars were made with Cowlitz and White river aggregates and five cements, and freezing and thawing were started at the end of a 30-day moist-curing period. A total of 77 cycles had little effect on any of the specimens. This is taken to mean that the aggregates from both sources are inherently sound and capable of producing durable concrete. After 77 cycles, freezing and thawing was discontinued and the bars were returned to moist storage at 70 deg. F. for a period of seven months. During this storage, values of dynamic E increased from 10 to 20 per cent. above the 30-day values. Freezing and thawing were then resumed and resulted in considerable difference in durability among the concretes made with the five cements. The order of durability with either aggregate was the same for the cements. Cement with 0.6 per cent. equivalent alkalis was the poorest. Cement with 1.06 alkalis was somewhat better. With this exception the order of durability is the same as that of the alkali contents of the cements. Cement with 0.26 alkali was virtually unaffected by freezing and thawing. The tests of part of the specimens were discontinued at the end of 155 cycles. The cement with 0.26 alkalis was carried through 220 cycles to establish its superiority more definitely.

It is evident that same change, presumably chemical in nature, took place within the concrete during the 7-month moist storage period and that the alkalis in the cements took part in this change. It should be noted that, during the original 77 cycles, the bars were subjected to intensive leaching during thawing. It is known that alkalis are leached rather readily from small concrete members. It is probable, therefore, that the full quantity of the alkalis originally in the cements was not present during the 7-month storage period. Leaching could account for the greater durability exhibited by the cement with 1.06 alkalis than by the cement with 0.6 alkalis since the alkalis in some cements are more readily soluble than in others.

There were 28 bars containing Cowlitz river aggregate in the laboratory which had been stored continuously in the fog-room for two years. This group included seven cements of varying alkali content (four bars of each cement). They had been tested periodically for dynamic modulus. All of these had gained at uniform rates proportional to the logarithm of the age. Freezing and thawing were started on these bars at the age of two years. During the first 77 cycles differences in alkali content of the cements were more pronounced in their effect on durability than in the previous series. In general, the degree of deterioration was proportional to alkali content. As in the previous series, the bars were stored an additional seven months in moist air at 70 deg. F., after which freezing and thawing were resumed. The gain in dynamic modulus which took place during the 7-month period was approximately offset by the next 13 cycles, after which the progress of deterioration continued at approximately the rate obtaining before the moist storage. This may be interpreted as meaning that chemical action with the alkalis in the cement had been largely completed during the initial two years of continuous moist storage at 70 deg. F. This does not mean similar completion of chemical reactions in two years' time under field conditions of lower average temperature and periodical drying.

Deterioration of concrete of the same type as in the structures in the vicinity of Mt. Rainier has not been found elsewhere on the State highway system of Washington. The cements used in these structures were high or medium-high in alkalis. This fact has led to investigations to study the possibility that unsatisfactory durability resulted from unfavourable reactions between high-alkali cements and the aggregates involved. There is little evidence to support or refute such a conclusion. There are no cases of the use of low-alkali cement with the aggregates involved, although low-alkali cement when used with other aggregates in one of the areas has given good service. Nor have the results been universally poor with all structures in which the troublesome aggregates have been used. Deterioration seems to have been conditioned by severity of exposure to moisture and cycles of freezing and thawing. The fact that disintegration has occurred nearly exclusively in handrails, footpaths, decks and wing walls illustrates the effect of exposure.

Lacking good field evidence, dependence has been placed upon the results of laboratory studies to determine the part that alkalis in cement have had in causing deterioration. The following three sand and gravel aggregates, one from each area under discussion, were selected for laboratory study: (1) An aggregate which results in abnormal expansion when used in roads with a cement that evidently was extremely high in alkalis. (2) An aggregate which has been used in many highway structures. (3) An aggregate used in highway structures of which most have been faulty. The properties of these aggregates are those usually associated with good durability. Mortar bar tests were made with the sands and crushed gravels from these pits. Negligible expansion, generally less than 0.02 per cent., has resulted in every case up to ages of two to four years. This has been true with both high-alkali and low-alkali cements and with 1 per cent. sodium hydroxide added to low-alkali cement. The tests indicate that these aggregates do not react with high-alkali cements in the same manner, or at least to the same degree, as those from Mt. Rainier, and they confirm the field observation that the type of deterioration is different. They might well be considered as definitely non-reactive were it not for the results of laboratory freezing and thawing tests. The results of freezing and thawing tests show that with one exception the first 77 cycles had very little effect on any of the specimens, indicating that the aggregates and cements each had characteristics making for good initial durability. Following the first 77 cycles the specimens were stored in a fog-room at 70 deg. F. for seven months. Upon resumption of freezing and thawing it became evident that changes, presumably chemical in nature, had taken place in certain specimens with the result that they were no longer resistant. In every case of poor resistance the cement was one of the three of highest alkali content. Good durability resulted in every case with cements lowest in alkalis. The cements were capable of making durable concrete as was shown by check tests with aggregate from another district.

Summarising the results of the freezing and thawing tests, it was found that (1) Good resistance resulted with each cement when combined with aggregate from another district. (2) Good resistance resulted with the two cements of

lowest alkali content when combined with each of the aggregates. (3) Poor resistance resulted with the three cements of highest alkali content when combined with three of the aggregates. These results appear to preclude the possibility that lack of durability with the latter aggregates was influenced appreciably by factors other than high-alkali content in the cement. Other tests also point to the alkali content of the cement as the main, if not the sole, factor determining durability.

The conclusions reached are that aggregates containing rock types derived from the lavas of Mt. Rainier react detrimentally with high-alkali cements and the type of reaction is similar to that reported by other investigators in a number of locations. These aggregates do not react harmfully with low-alkali cements as indicated by laboratory tests and by excellent results in existing structures, some of which have reached the age of 19 years. Laboratory studies indicate that poor resistance is primarily a function of the alkali content of the cement. These results point to the need of limiting the alkali content of cements for use with many aggregates in Washington. The present tests, however, do not furnish sufficient data to determine definitely the safe upper limit of alkalis.

A Soviet Cement Plant.

THE Proletary cement works in Novorossisk, built in 1882, is the oldest cement works in the Soviet Union. Before the war the works was producing 700,000 tons of cement per annum. The Germans entered Novorossisk in September, 1942, and fighting raged on the territory of the cement works for a year; it was there the Germans were stopped. The cement works suffered heavy damage during the fighting, and in their retreat the Germans blew up the works and destroyed the houses in which the workers lived, schools, clubs, and children's institutions. The works has now been restored and cement was again produced in May, 1944. By November the first section of the narrow-gauge railway was restored, as well as an aerial ropeway, $1\frac{1}{2}$ kilometres in length. In the last eight months of 1944 the works has produced thousands of tons of cement. Plans for 1945 call for complete mechanisation of the enterprise and the installation of additional machinery.

The Capping of Concrete Test Specimens.

AN investigation made on the influence of type and age of cap on the apparent strength of concrete cylinders indicates that the age of the caps has an important bearing on the apparent strength of the concrete, one hour being the minimum time required for the best of the materials to develop the full strength of the concrete. The results of the investigation are reported by Mr. T. B. Kennedy in the "Journal of the American Concrete Institute," No. 11, 1944, where it is stated that the U.S. Army Corps of Engineers' laboratory had been using, for almost two years, a commercial sulphur-silica compound (compound "A") for capping test specimens, when it was discovered that specimens capped with this compound did not attain the strength at ages up to 5 hours after capping that they did when the caps were 20 to 24 hours old. The fact was discovered when a series of relatively high-strength specimens was being tested. All the specimens were capped on one day but only half were tested that day, the remainder being tested the day following. It was found that those tested the day after capping had attained an average relative strength of 123 per cent. compared with those tested the same day that they were capped.

This observation led to a limited programme in which the following features were investigated:—

(a) Two sulphur-silica compounds ("A" and "B") were compared, the latter being a sulphur-silica product of known high strength which had been used in the laboratory prior to the use of compound "A." Both materials were used to cap a series of specimens with two end conditions, one with plane parallel ends, and the other with the bottom end plane and the top end stepped $\frac{1}{4}$ in. over one-half of the area. The specimens were tested at varying intervals after capping to determine the rate of strength gain of the two materials.

(b) Compound "B" was compared with two gypsum products: one (compound "C") was a "medium-strength" material, and the other ("D") was a "high-strength" material. Compounds "C" and "D" were similar in appearance and in general action to plaster-of-Paris. The effect of varying time intervals between capping and testing was studied for each material.

(c) Compounds "B" and "D" were used in determinations of the difference in apparent strength caused by variation of thickness of caps.

All the tests were made on standard 6 in. by 12 in. concrete cylinders, using a 300,000 lb. testing machine. The concrete used for the test specimens was varied. A total of 252 cylinders was made and tested. All sulphur-silica caps were $\frac{1}{4}$ in. thick except on those cylinders which were capped with varying thickness of caps to study the effect of thickness upon the apparent strength. The sulphur-silica compounds were heated in electric thermostatically controlled pots to a temperature of 248 deg. F. The plaster caps were formed using squares of $\frac{3}{8}$ in. thick plate glass pressed into the plaster to produce as thin caps as possible not exceeding $\frac{1}{16}$ in. in all cases except where thicker caps were desired to study the effect of the thickness of caps. Compound "C" was mixed in the

proportion 1 part of water to 3 parts of "C" by weight, and compound "D" in the proportion 1 part of water to 3.57 parts of "D" by weight. All concrete cylinders were cured in a fog-room in an atmosphere of 100 per cent. relative humidity and a temperature of 70 deg. F.

The conclusions reached are as follows: (1) All sulphur-silica compounds do not act alike. Compound "B" developed adequate strength within 1 hour after capping, while compound "A" continued to gain strength up to 40 hours, and possibly longer. The strength at 1 hour to 5 hours was approximately 84 per cent. what it was at 40 hours. (2) The stepped-end condition did not appreciably alter the apparent compressive strength developed when the capping was done with either compound "A" or "B" and an appropriate age of cap. (3) For the three classes of concrete tested there seemed little to choose between compounds "B," "C," or "D." It would appear that 1 hour is sufficient time to allow all three capping materials to harden. However, compounds "C" and "D" gave slightly higher results at an age of 3 hours. Of the two gypsum materials compared, "C" is cheaper but somewhat less desirable to use than compound "D." "C" hardens in approximately 15 minutes after the addition of water and occasionally sticks to the glass plates. "D" hardens in approximately 30 minutes and no trouble was experienced with sticking. (4) Caps of either sulphur-silica compound "B" or the gypsum compounds "C" and "D" should be made as thin as possible. (5) A minimum period of 1 hour between capping and testing appears to be essential in order that the caps may be strong enough to distribute the load evenly to the specimens. (6) Ease of operation, speed with which specimens can be capped, and the fact that compound "B" may be re-used, make it the most economical and desirable of the four materials tested for capping standard 6 in. by 12 in. concrete test specimens.

U.S. Restrictions on Special Cements.

EARLIER in the war, when the demand for Portland cement reached record levels, the United States War Production Board prohibited the manufacture of more than three types of Portland cement in order that the industry might concentrate on the types that were mostly required for Government work. As was stated in this journal for October, 1942, the three permitted types were ordinary Portland cement, rapid-hardening Portland cement, and a cement for use where moderate heat of hydration or a moderate resistance to sulphate action was required. These restrictions have now been removed.

When the restrictions were issued in 1942 the total consumption of cement in the United States was 185 million barrels a year. The capacity of the industry is now 215 million barrels a year, the consumption in the year 1944 was 88 million barrels (40 per cent. of capacity), and the anticipated consumption in the year 1945 is between 50 and 60 per cent. of capacity.

Feeding Admixtures Uniformly.

A METHOD of feeding accurately and uniformly small percentages of admixtures to Portland cement has been devised by Mr. J. F. Barton, chief chemist of the Federal Portland Cement Company, of Buffalo, U.S.A. The machine was specially made for the incorporation in cement of Vinsol resin to produce air-entraining cement. The amount of the addition is specified as 0.025 per cent. to 0.045 per cent. of the weight of the cement. If one assumes that an average grinding unit will produce 10 bags of cement per hour then $6\frac{1}{2}$ lb. of Vinsol resin must be fed continually and proportionately over a period of one hour with 22,553 lb. of cement. To accomplish such a small feed rate obviously requires special equipment or costly expenditure of man hours. The feeder described was put into use in June, 1942, and has proved successful in the handling of powdered and flake Vinsol resin, calcium stearate, aluminium stearate, hydrated lime, and carbon black. It is believed by the inventor that the principle involved in the machine is equally adaptable to many other dry light-weight materials, and particularly to resins and other organic acids of a sticky nature. Very light weight, fluffy, free-flowing material such as hydrated lime is handled with ease.

The feeder consists essentially of a supply hopper or reservoir connected with a feeding device and a horizontal revolving plate. Agitation is provided inside the reservoir which ensures positive flow of material into the feeding mechanism. The feeding mechanism controls and delivers the materials in measured quantity to the revolving plate. An adjusting medium is provided to permit regulation of the position and rate of flow of material to the plate. A micrometer-adjusting plough is provided for the purpose of further adjustment for ultimate quantity and for diverting the material from the revolving plate into the grinding system.

The feeder is primarily designed for use in connection with all types of clinker feeders. Due to the slowness of operation of the machine when feeding small quantities a gear-head motor is required to drive the mechanism if an independent drive is desired. However, when proportioning two or more ingredients, as is done in any Portland cement grinding operation, a higher degree of blending is assured when all feeding mechanisms are synchronised to a central drive. In this type of feeding arrangement, uniformity of blending is not thrown out of balance as is the case with independent feeding. With independent feeding, the feed rate of one material can change radically with no change being effected in the speed of the other mechanism; however, a central drive causes a proportionate rate change if the main drive mechanism is changed in speed. It is recommended that the feeder be synchronised with central feeding control. The feeder permits operation at a much higher rate of speed than is necessary when feeding Vinsol resin. It has a wide range of limited capacity for feeding various materials depending on the speed of operation. When operating at reduced speed the range in feed rate can be varied from zero grammes per minute to 300 grammes per minute. This range provides sufficient capacity to accommodate a cement production rate of approximately 60 tons per hour. The supply reservoir on the

present model has a capacity for ten hours of Vinsol resin requirement at 30 tons per hour production rate. Two feeders are now in operation with powdered Vinsol resin, and they are showing a feed rate variation of less than 1 gr. per minute.

Recent development in the feeding of Vinsol resin in the liquid or neutralised form is rapidly being adopted in the hope of overcoming some of the difficulties encountered in feeding dry resin. This method, however, is not without its problems and lack of uniformity in feeding.

Influence of Cement on the Cracking of Concrete.

AFTER a review of the formation of cracks in Portland cement concrete in "Zement" (1943, vol. 32, Nos. 7, 8, 9 and 10), H. Mussnug reaches the following conclusions: An improvement in the cement properties is obtained by increasing the calcium silicates and reducing the calcium aluminates. Cement obtained from a mix with a high silica content—the lime saturation being the same—is, in general, superior to that from a mix of lower silica content in respect of the development of strength, and especially of the end-strength, as well as of shrinkage. It is doubtful, however, whether an improvement of the cement in this way would have any fundamental effect on the problem of cracking; it would, however, be almost certain to reduce the risk of cracking. The tricalcium silicate content is known to be of great importance for cement strength. In practice, an increase in the tricalcium silicate content of the clinker means an increased lime saturation of the mix. By the use of fluxes the lime saturation and consequently the tricalcium silicate content can in many cases be increased considerably. The reaction in the kiln depends, however, not only on the mix components but also on the conditions of burning; if, for example, the kiln is greatly overloaded the reaction will be unfavourably affected. As an improvement of some importance in practice in cement properties is obtained by increasing the silica, sufficient consideration should be given to the silica modulus also in designing the mix. The conditions of burning have been found to have an important effect on the strength of the cement obtained, but the rate of cooling the clinker has no influence of any importance.—Building Science Abstracts, August, 1944.

APPOINTMENT.—The directors of Messrs. Edgar Allen & Co., Ltd., elected Mr. William H. Higginbotham as chairman of the company in succession to the late Mr. C. K. Everitt, whose death occurred on February 6. Mr. Higginbotham joined the company in 1930 as secretary and became a director in 1933.
